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Review

A questionnaire-based review of the operational use of remotely sensed data by national forest inventories

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ABSTRACT

We report on the operational use of remotely sensed data by national forest inventory (NFI) programmes in 45 countries representing approximately 65% of the world's forest area. The analysis is based on responses to a questionnaire prepared under the auspices of COST Action FP1001 "Improving Data and Information on the Potential Supply of Wood Resources: A European Approach from Multisource National Forest Inventories (USEWOOD)". Responses were received from NFI remote sensing experts from both European and non-European countries. Three major conclusions were drawn from the study: (1) remote sensing now plays an essential role in many NFI programmes and provides data that can be used to enhance estimates for the most meaningful and commonly reported forest resource parameters; (2) a wide spectrum of remote sensing methods are currently used by NFI teams; and (3) although substantial effort and attention has been focused on the use of aerial photography and spaceborne sensor data for mapping and enhancing estimation, integration of uncertainly estimation requires additional attention.

The operational use of remotely sensed data by NFI programmes is illustrated for three case studies: a case study for Switzerland focuses on digital aerial photography, a case study for Finland focuses on spaceborne sensor data for small area estimation, and a case study for the USA focuses on spaceborne sensor data for increasing the precision of large area estimates. Although use of remotely sensed data by NFI programmes may remain region-specific and some approaches are not readily transferable, generally applicable good practice guidelines were formulated on the basis of the questionnaire responses and the case studies. These guidelines are intended to promote better use of limited financial resources and to increase the accuracy and precision of NFI estimates.

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1. Introduction

Capitalizing on development work spanning several decades and in some cases more than 100 years, technologically advanced national forest inventory (NFI) programmes using statistical sampling have been established in many European and non-European countries (Tomppo, Haakana, Katila, & Peräsaari, 2008; Tomppo, Olsson, et al., 2008, Tomppo et al., 2011; Lawrence, McRoberts, Tomppo, Gschwantner, & Gabler, 2010). The earliest NFIs were established in the Nordic countries and the United States of America (USA) and focused on the continued availability and supply of timber with an emphasis on acquiring information related to forest area, volume and growing stock increment (LaBau, Bones, Kingsley, Lund, & Smith, 2007; Tomppo, Haakana, et al., 2008, Tomppo, Olsson, et al., 2008, Tomppo et al., 2011). Later, NFI programmes introduced new variables and new sample designs to estimate non-timber attributes related to biodiversity (e.g., naturalness, forest structure, deadwood volume) and forest health (e.g., crown vitality, defoliation) (Tomppo, Gschwantner, Lawrence, & McRoberts, 2010, NFI Report Chapters 1–37).

NFI plot-based, in situ surveys integrated with aerial photography and spaceborne sensor data both serve the requirement for ever more diverse and detailed forest statistics and produce relevant spatially explicit products. Remotely sensed data have been incorporated into operational forest inventories, and estimates enhanced through the use of remote sensing-based maps can now be expressed in forms similar to sample-based estimates. McRoberts and Tomppo (2007) list four primary ways by which remote sensing approaches enhance NFIs: (1) providing faster and less expensive methods for estimating forest attributes; (2) increasing the accuracy of large area inventory estimates, often via stratified or weighted estimation; (3) providing inventory estimates with acceptable bias and precision for small areas for which sufficient field data are not available; and (4) producing forest thematic maps that can be used for purposes such as timber production, procurement, and ecological studies.

Historically, interpretation and mapping of trees and stands based on aerial photography have represented the most popular form of remote sensing of forests (Spurr, 1960). Aerial photography is the oldest and most frequently used form of remote sensing and was first used to aid stratification during the 1940s and 1950s by the Forest Inventory and Analysis (FIA) programme of the U.S. Forest Service (Bickford, 1952; LaBau et al., 2007) and by Spain and Switzerland in the 1960s and late 1970s, respectively (Martinez & Condes, 1997; Brassel & Lischke, 2001). The increasing availability of aerial photography in digital formats and the ease of integration with auxiliary and other GIS data has greatly facilitated its use (McRoberts & Tomppo, 2007). From an operational perspective, considerable cost savings may be realised by initially observing NFI plot locations using aerial photography or high resolution satellite photography.

NFI country reports (Tomppo et al., 2010) and other surveys (Köhl & Päivinen, 1996) indicate that aerial photography continues to be widely used by European NFI programmes. Koch (2013) identifies multiple reasons for continued use of aerial photography: (1) long tradition; (2) fine spatial resolution;(3) greater probability of acquiring cloud free data within a specific time window; (4) close cooperation between survey institutes acquiring photography and forest authorities; (5) relatively large costs for very high resolution satellite data; and (6) the relative ease of capturing smaller European survey areas using aerial photography when compared to larger non-European countries such as the USA, Canada, or in South America.

In countries outside Europe, NFI use of earth observation data from satellites is more common (Lawrence et al., 2010; FAO, 2008; Koch, 2013). The integration of remotely sensed satellite data with field inventory data for the estimation of forest parameters dates back to the 1980s (e.g. Poso, Hame, & Paananen, 1984; Halme & Tomppo, 1987; Danson, 1987; Tomppo, 1988). Techniques such as the k-nearest neighbours (k-NN) method were subsequently refined and further developed for regional applications in the USA (Franco-Lopez, Ek, & Bauer, 2001; McRoberts, Nelson, & Wendt, 2002a) and operationally at national scales in Finland and Sweden in the 1990s and 2000s (Reese et al., 2003; Tomppo, Haakana, et al., 2008). The opening of the Landsat archive, making the entire historical time series of data freely available, greatly facilitated the use of satellite imagery (Loveland & Hansen, 2012). Satellite-based methods were first implemented operationally as part of the Finnish multi-source NFI (MS-NFI) by Tomppo in the early 1990s (Tomppo, 1991; Tomppo et al., 2011). Similar approaches to those in Finland and the USA for integrating NFI and field plot data with Landsat data have been tested in Norway (Gjertsen, 2007), Ireland (McInerney, Pekkarinen, & Haakana, 2005), Austria (Koukal, Suppan, & Schneider, 2007), Italy (Maselli, Chirici, Bottai, Corona, & Marchetti, 2005) and Brazil (Vibrans, McRoberts, Moser, & Nicoletti, 2013).

Other earth observation systems, such as synthetic aperture radar (SAR) or polarimetric SAR interferometry (Praks, Kugler, Papathanassiou, Hajnsek, & Hallikainen, 2007; Hajnsek, Kugler, Seungkuk, & Papathanassiou, 2009) have been tested and used to estimate forest variables over large areas. In particular, the use of airborne laser scanning (ALS) data in combination with NFI plot information has increased in recent years and has been shown to be effective for enhancing the estimation of forest inventory attributes (Naesset, 2007; Vastaranta et al., 2013; Wulder et al., 2013; McRoberts, Næsset, & Gobakken, 2013). Although data from these sensors have yet to be used operationally for national-level strategic assessments by NFIs, they are used operationally for stand-level forest management inventories in Finland, Norway and Sweden.

Despite the increasing operational use of remotely sensed data by NFIs, practical information on the detail, scale and approaches used has not been readily available in a consistent format. Therefore, one of the overall objectives of COST Action FP1001 "Improving Data and Information on the Potential Supply of Wood Resources" was to provide such information. COST (European Cooperation on Science and Technology) is a European framework for promoting and facilitating scientific cooperation among European scientists and researchers (COST, 2014). COST Action FP1001 focused on European approaches for using MS-NFI data to improve information on the potential supply of wood resources (COST FP1001, 2014). The specific objectives of the study reported herein were threefold: (1) to summarise information on the operational use of remotely sensed data by both European and non-European countries via responses to a questionnaire survey; (2) to illustrate state-of-the-art remote sensing support for NFIs via case studies; and (3) to provide good practice guidelines for use of remotely sensed data by NFIs based on responses to the questionnaire and the case studies.